



SAFESKY: Developing an enterprise strategy for aviation radiation risk management

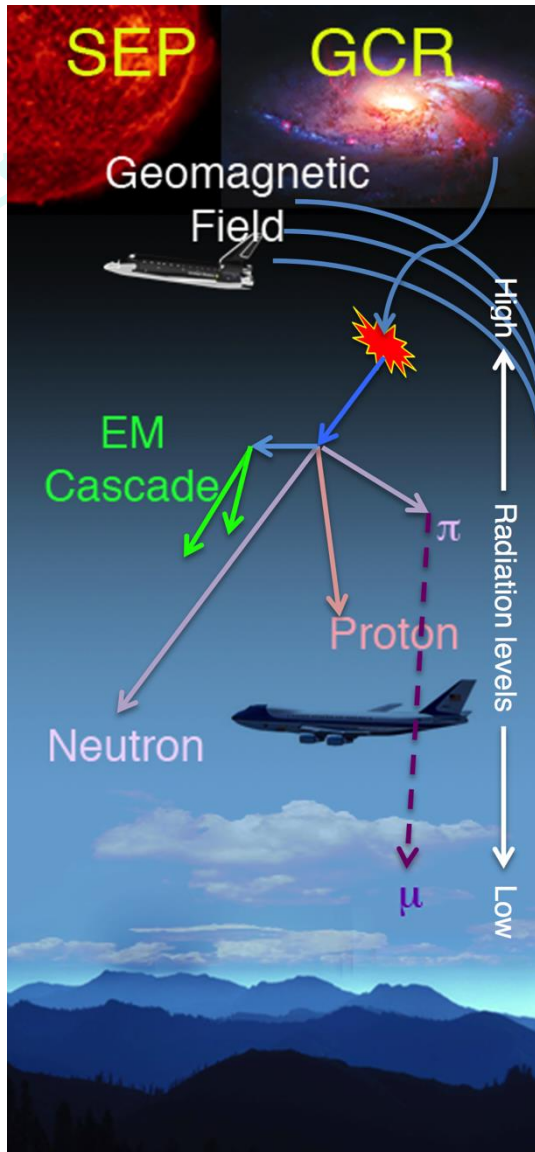
Space Weather Workshop 2017

May 5, 2017

**W. Kent Tobiska
Space Environment Technologies**



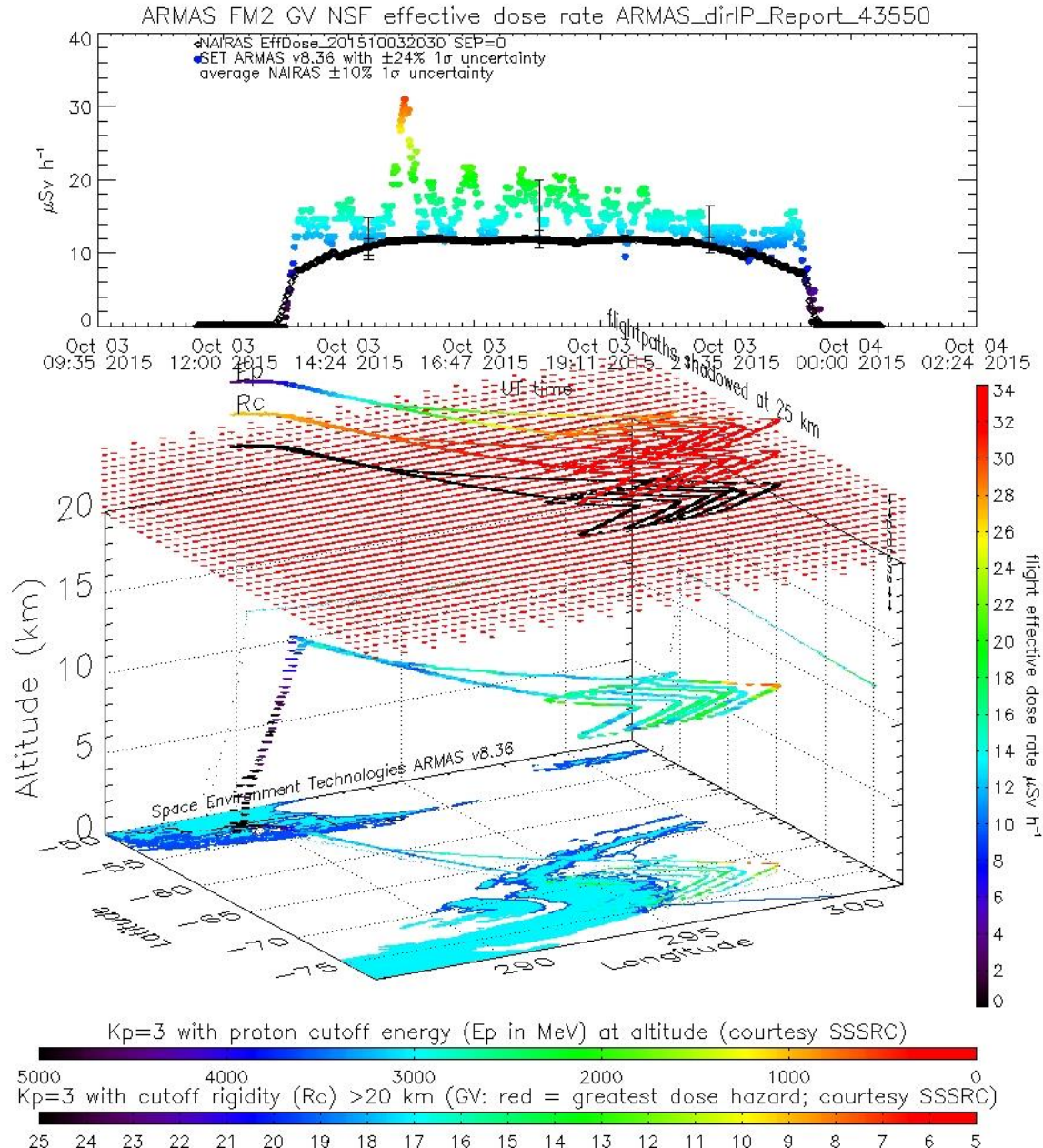
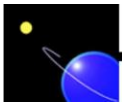
Background to aviation radiation activities – community goals and progress



Space weather creates a
dynamic radiation
environment at aviation
altitudes

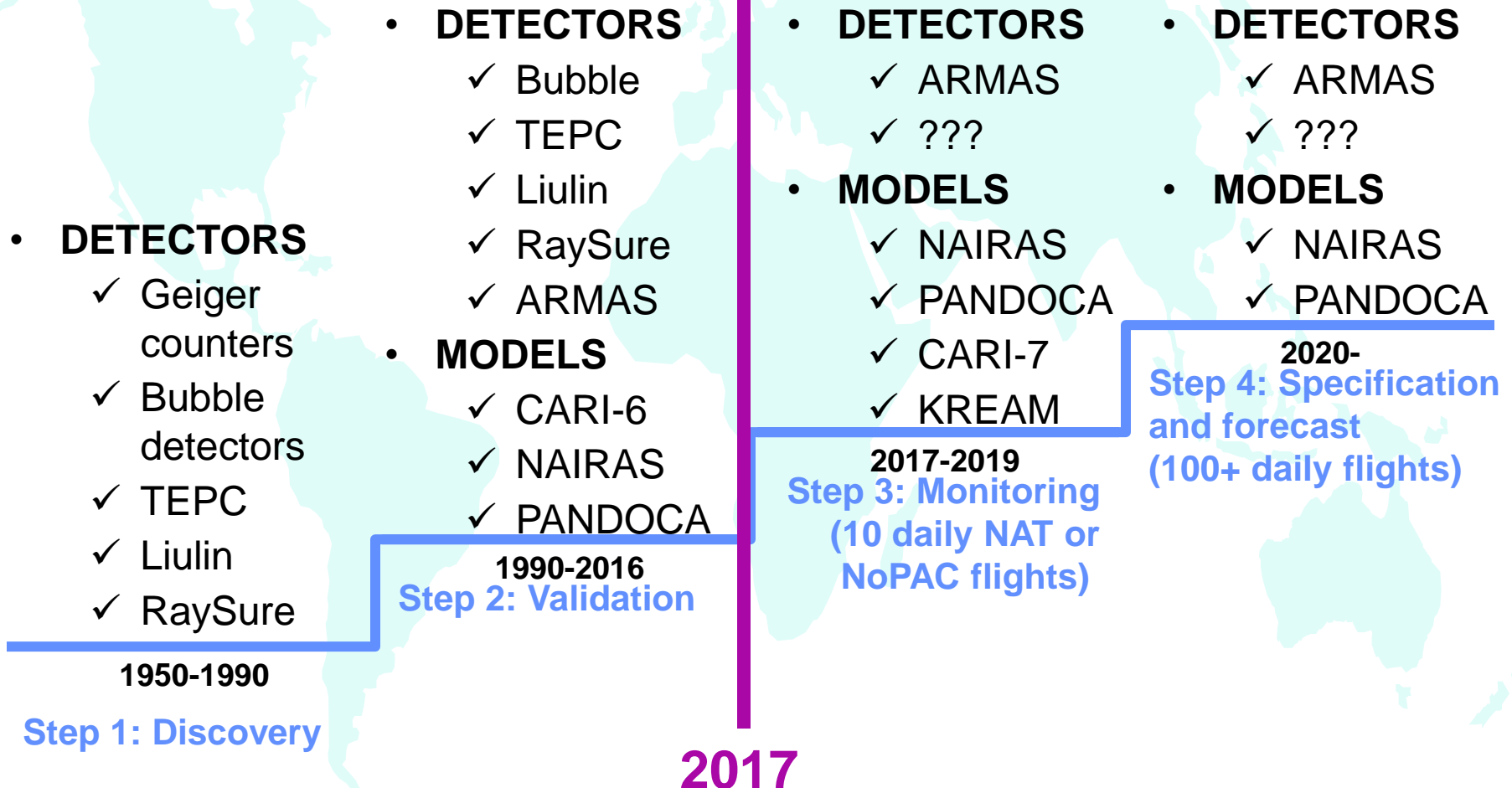
Aviation radiation exposure can come from

- ✓ global phenomenon GCRs (career health issue)
- ✓ high latitude phenomenon
 - ✓ Extended major events SEPs (fleet operations and aircrew/passenger safety issue)
 - Possible short-term minor events non GCR, non SEP (career health issue)?





Where are we today? Progress towards aviation radiation specification & forecast

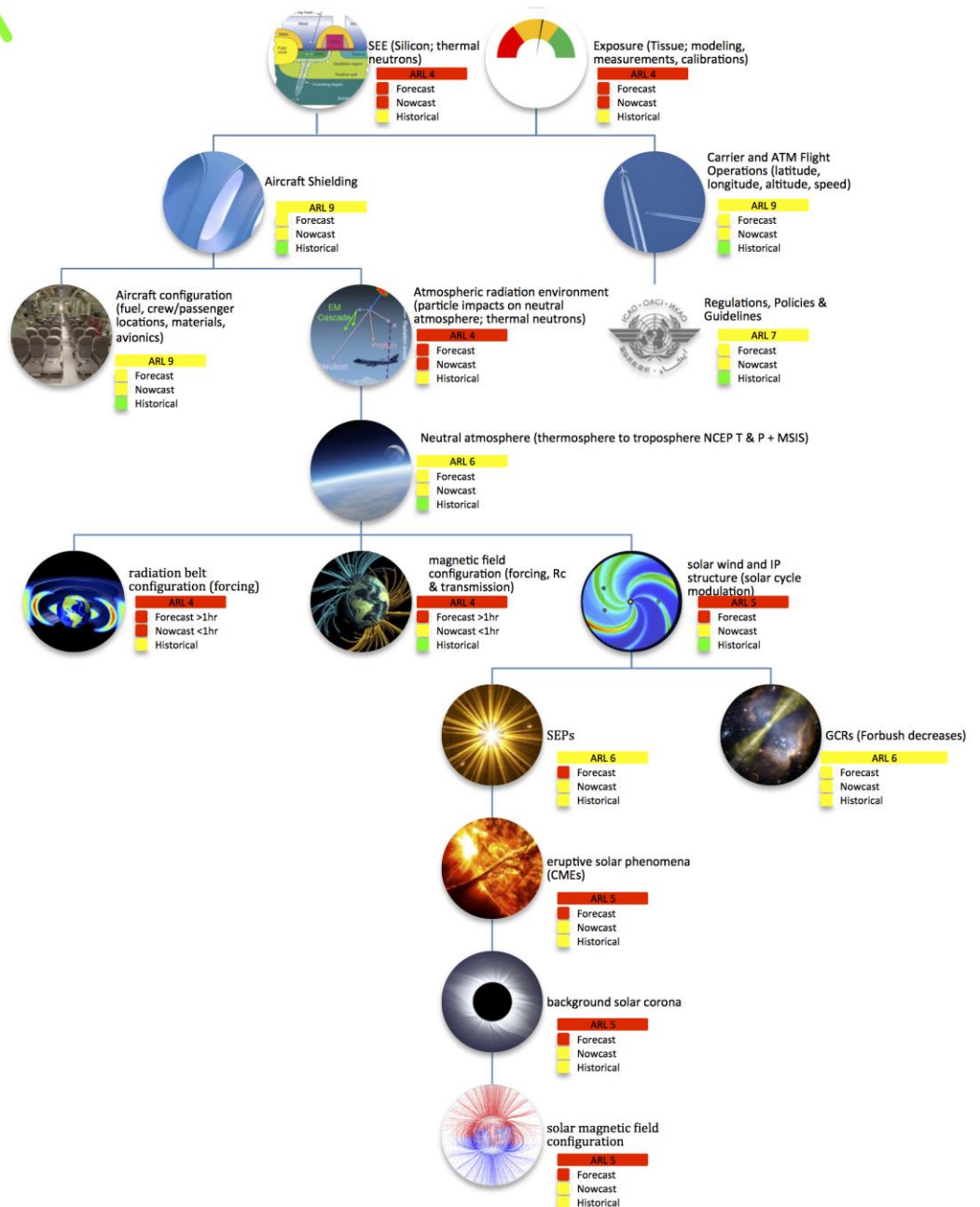


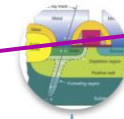
SAFESKY ROADMAP

Tobiska

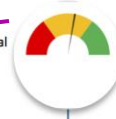
Roadmap for Aviation Radiation Safety

PRIORITY





SEE (Silicon; thermal neutrons)
ARL 4
Forecast
Nowcast
Historical



Exposure (Tissue; modeling, measurements, calibrations)
ARL 4
Forecast
Nowcast
Historical



Exposure (Tissue; modeling, measurements, calibrations)

ARL 4

Forecast
Nowcast
Historical

SAFE
ROAD

Pr



SEPs

ARL 6
Forecast
Nowcast
Historical



GCRs (Forbush decreases)

ARL 6
Forecast
Nowcast
Historical



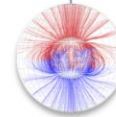
eruptive solar phenomena (CMEs)

ARL 5
Forecast
Nowcast
Historical



background solar corona

ARL 5
Forecast
Nowcast
Historical



solar magnetic field configuration

ARL 5
Forecast
Nowcast
Historical



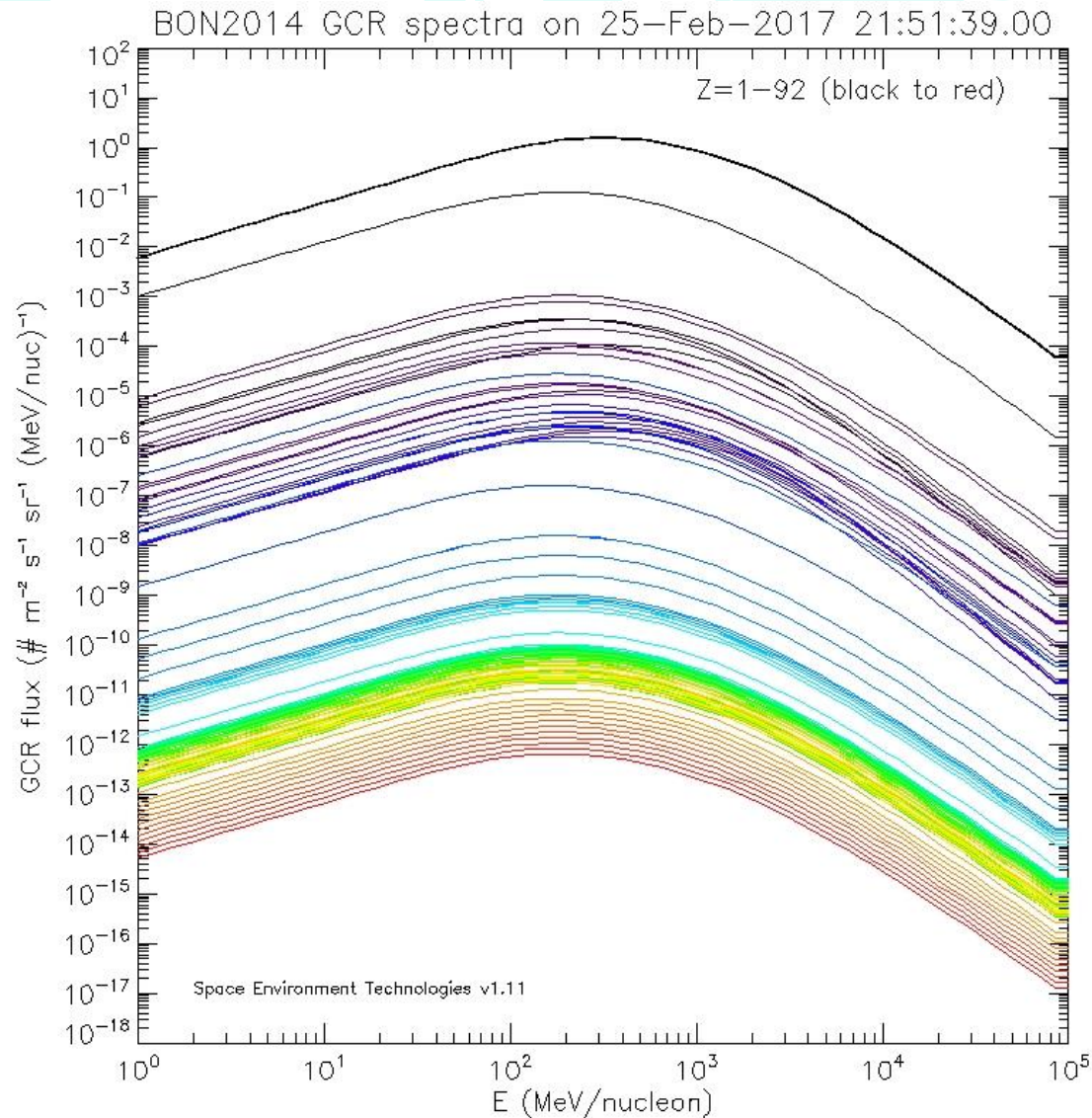
Backup slides



**GCR, SEP, TP spectra and
Rc produced for models
that can be used for
operational end users –
what improvements are
needed?**

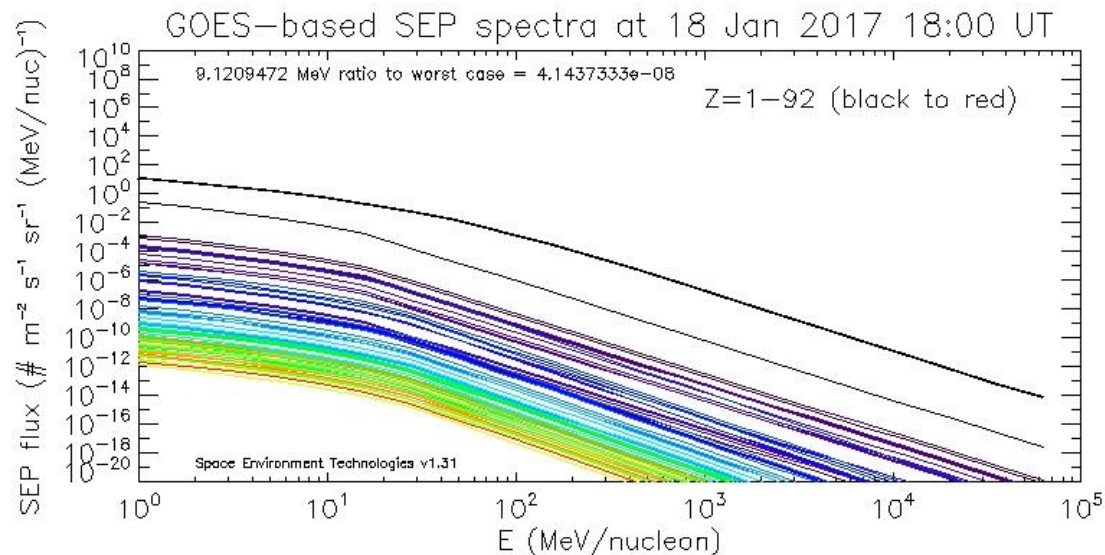
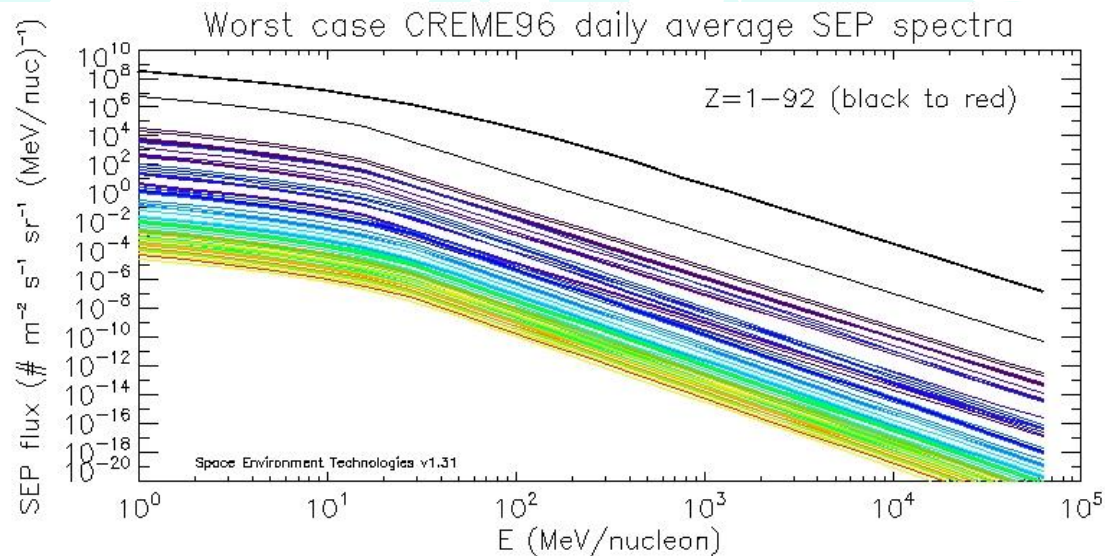


GCRs produced for operational models



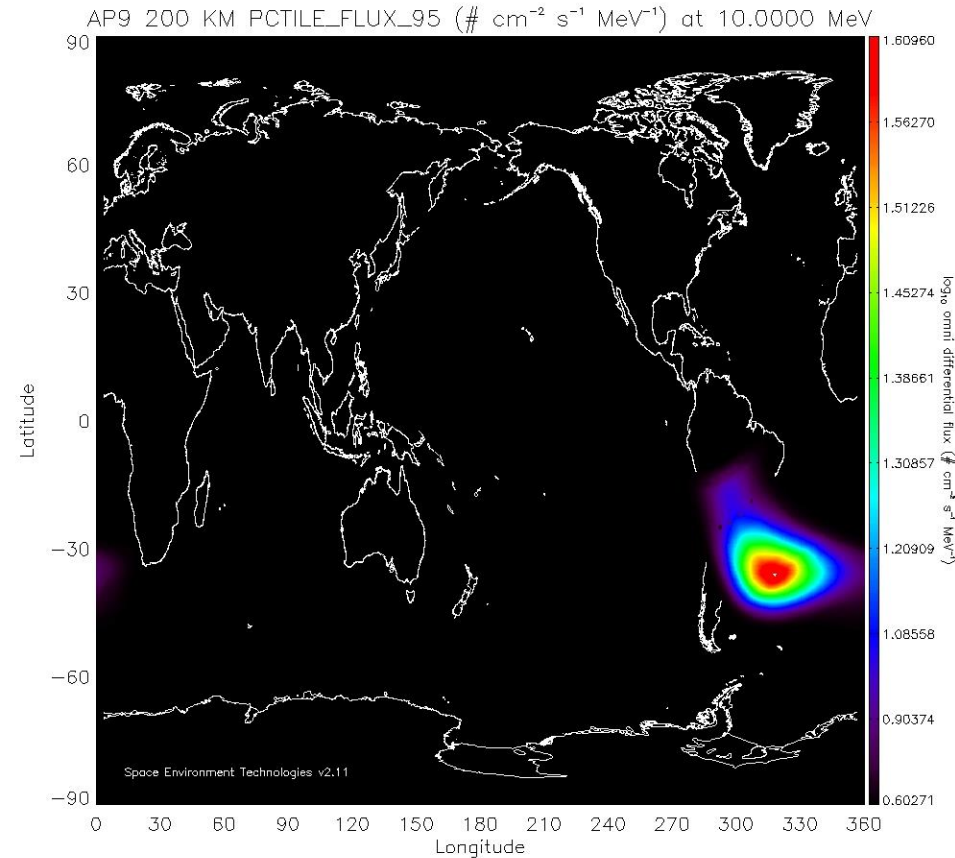
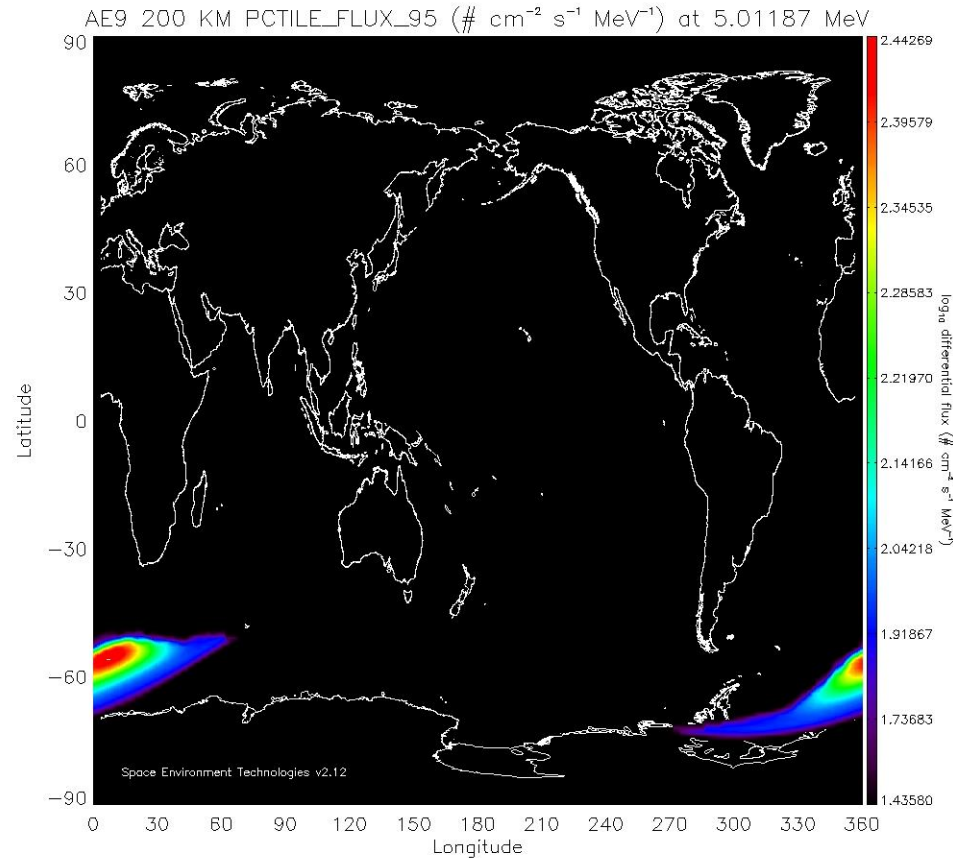


SEPs produced for operational models



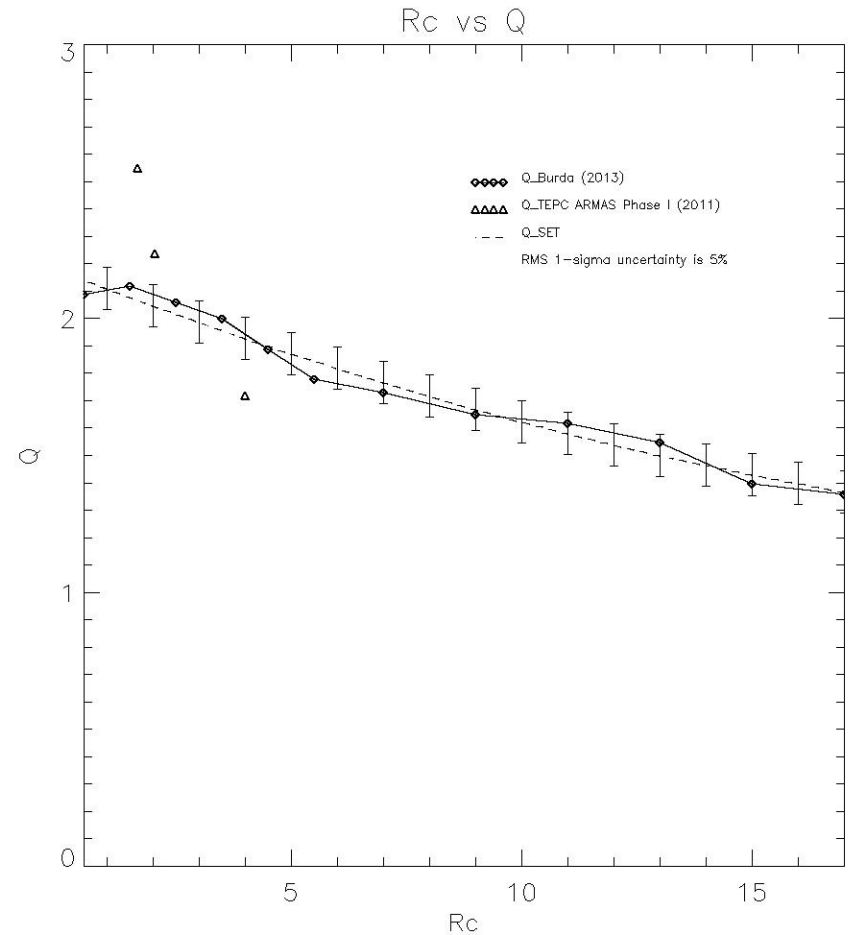
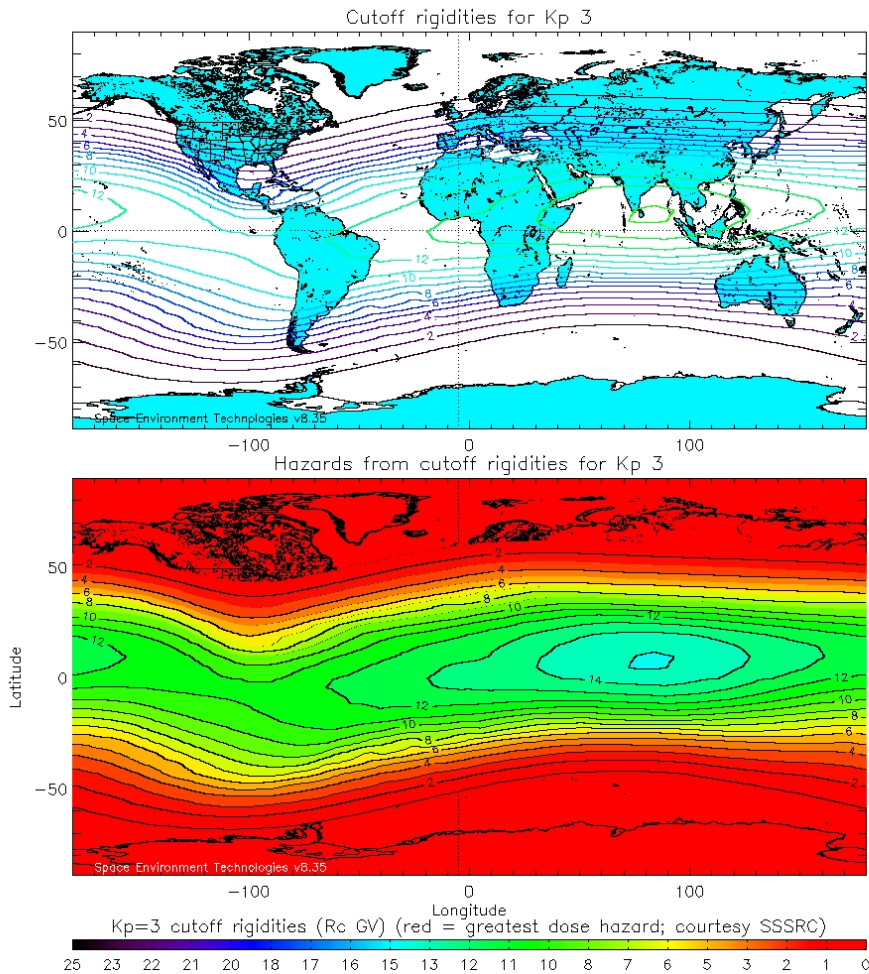


TPs produced for operational models





Rc produced for operational models → Q?





Instruments – what instrument advances and campaigns will be needed?



Far West Hawk TEPC Dosimeter

- TEPC-Tissue Equivalent Proportional Counter (dose to humans) and the TEPC is a true Micro-dosimeter
- Gas filled active micro-dosimeter with 2 μm diameter spherical volume of human tissue equivalent plastic
- Measures absorbed dose (D) and dose equivalent (H) to tissue in mixed radiation fields
- Hawk is self contained, battery powered, passive and GPS equipped
- Provides a radiation quality factor (Q)
- Flew on AFRC/ER-2 in the 1990s
- Flown on United and Virgin Atlantic 747s
- Placed in aluminum suitcase in overhead storage
- Designed for aircraft, used on Space Shuttle, Mir & ISS

Hawk TEPC

Spectrometer,
includes power
and data storage

Active volume





Liulin

- Absorbed dose in silicon measurements
- Developed in Bulgaria
- 3699 flights for 133,438 $H^*(10)$ records with 5 min resolution covering one solar cycle from 2001 to 2011





Raysure

- Absorbed dose in silicon measurements
- Developed in UK
- Calibrations at LANSCE and flight on RaD-X





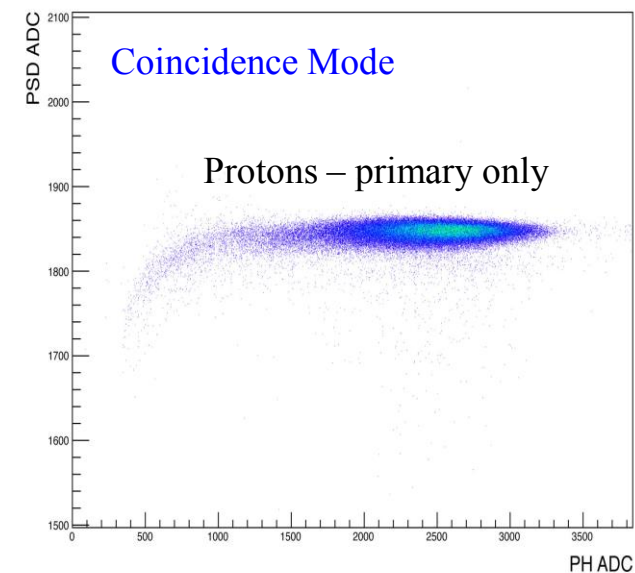
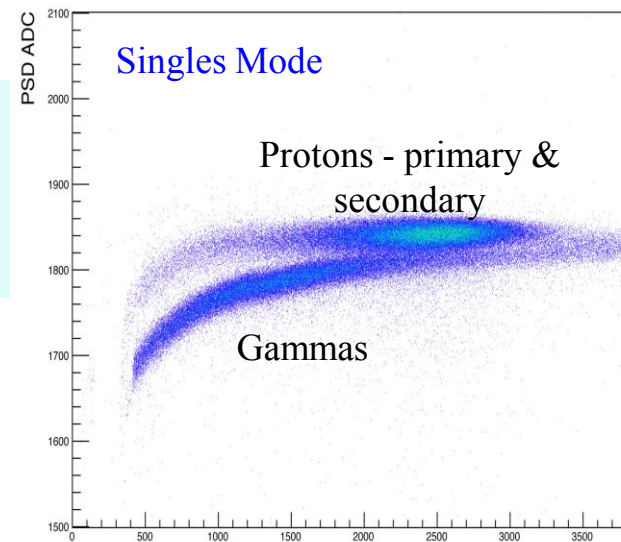
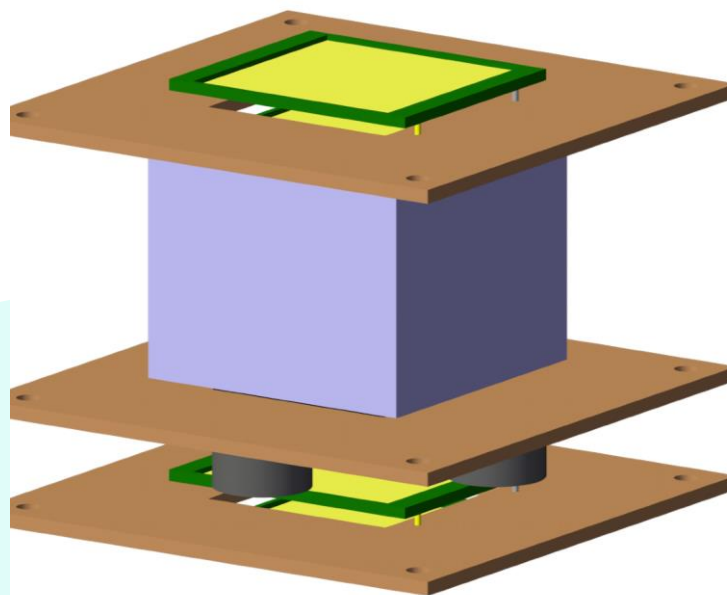
ARMAS

- Absorbed dose in silicon measurements
- Teledyne/Aerospace Corporation technology
- Calibrated real-time dose rates through Level 4 data produce (effective dose rate)



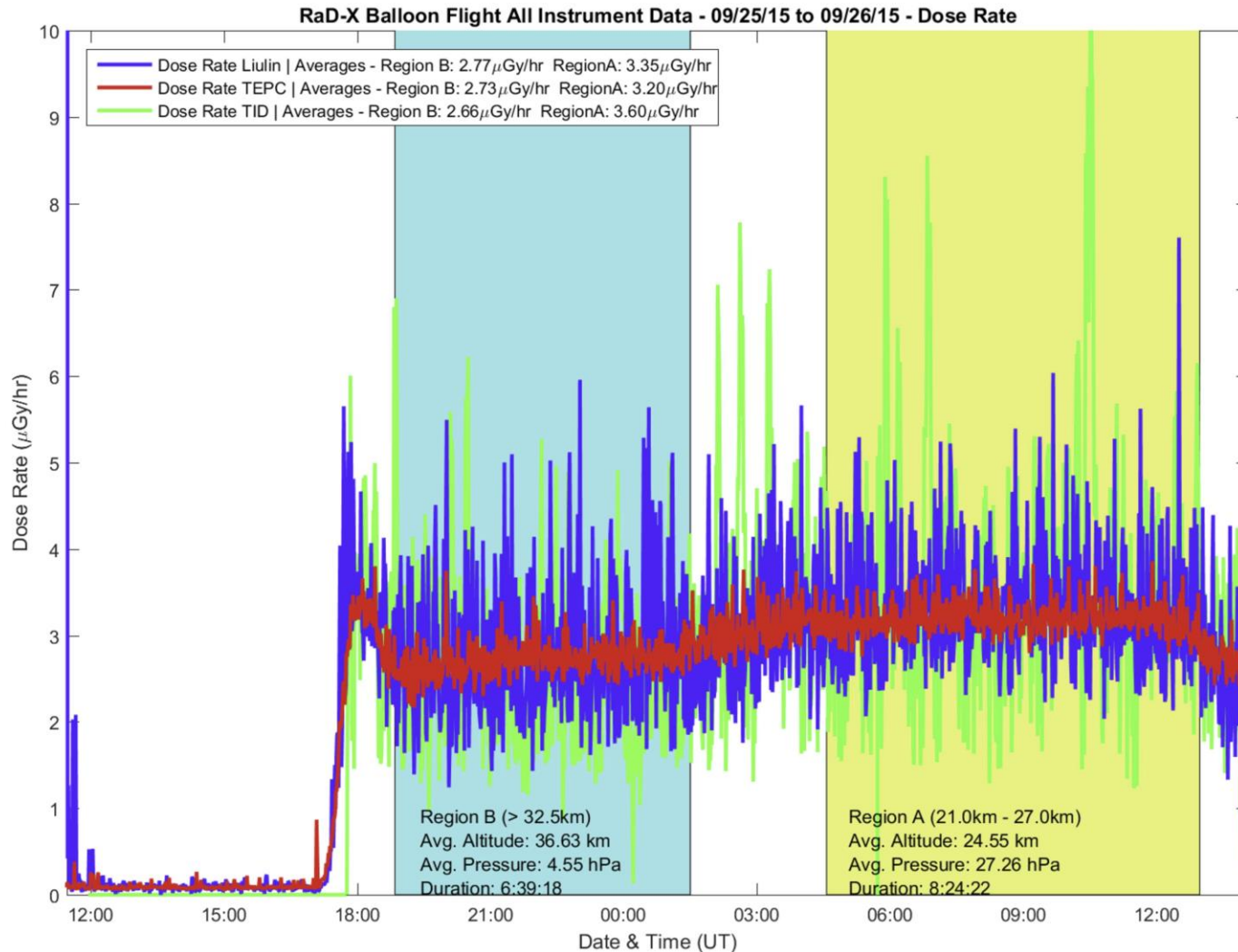


DOSEN





RaD-X campaign





Example of ARMAS for real-time total absorbed dose rate (Si) data acquisition



ARMAS Objective:

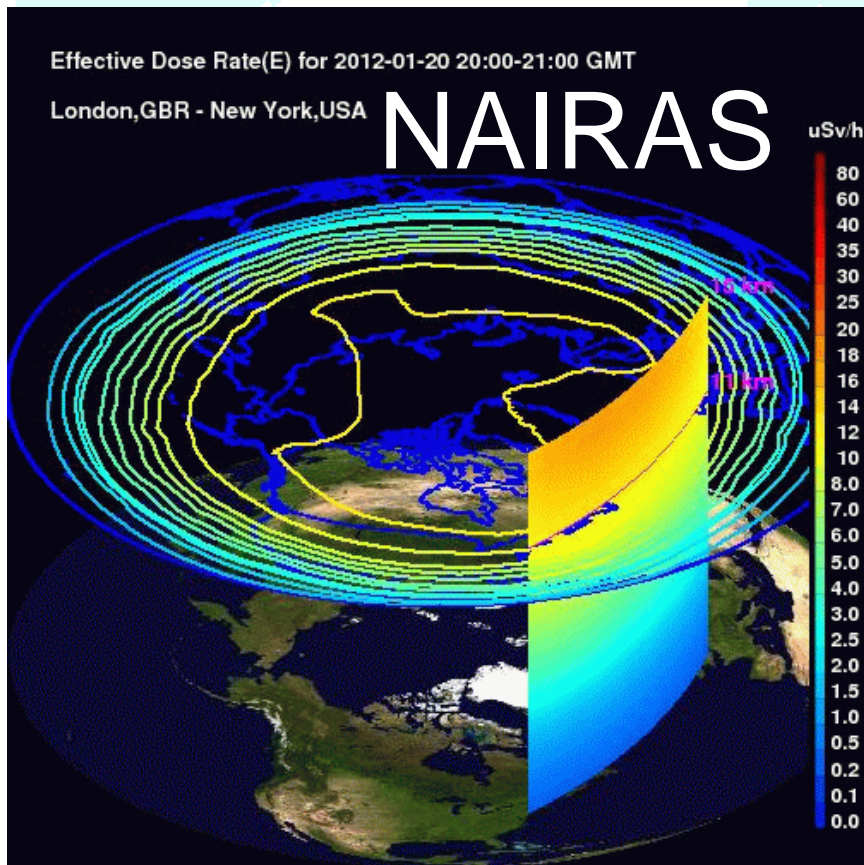
Build an **accurate, calibrated, and real-time operational system** to measure, report, and model aviation radiation for use by air crew, aircraft operators, air traffic management, and the flying public



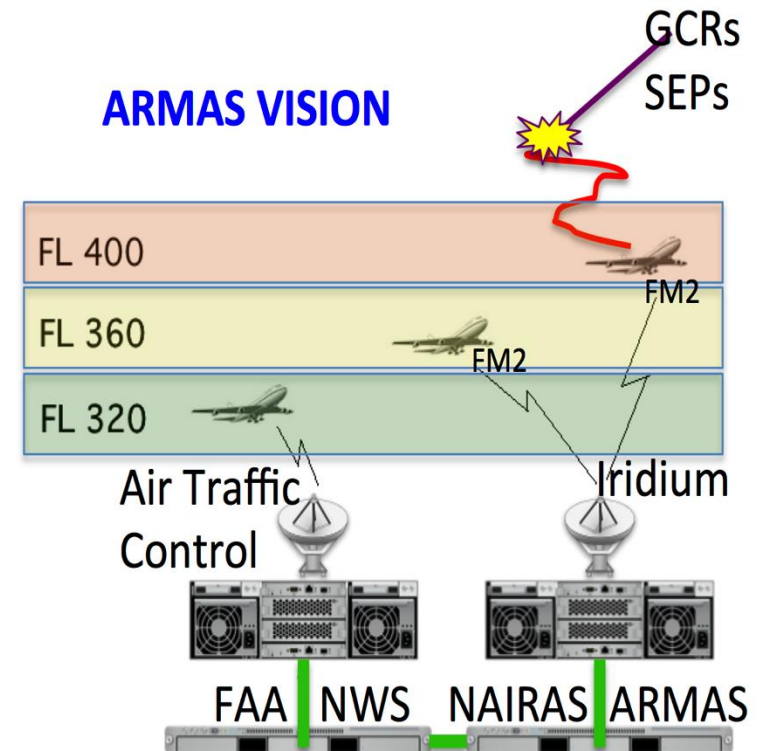
NAIRAS plus ARMAS

Real-time global aviation
radiation climatology

Real-time local aviation
radiation measurements



ARMAS VISION



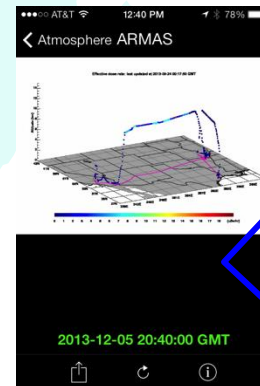


ARMAS real-time measurements demonstrated

292 NASA DC-8, NASA ER-2,
NOAA G-IV, NSF G-V, and
commercial Boeing/Airbus/Embraer
flights from 2013 into 2017



**ARMAS Flight Module 1
(FM1) on NASA AFRC DC-8**





Two ARMAS FM2 units were deployed in 2015

- **Korea Space Weather Center** purchased two FM2s as part of ARMAS Phase IIE commercialization
- FM2s were deployed to **NOAA G4** and **NSF G5** in Feb-Mar 2015
- Data became available to the community starting in June 2015



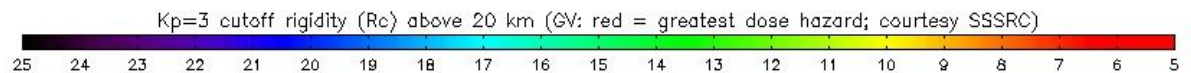
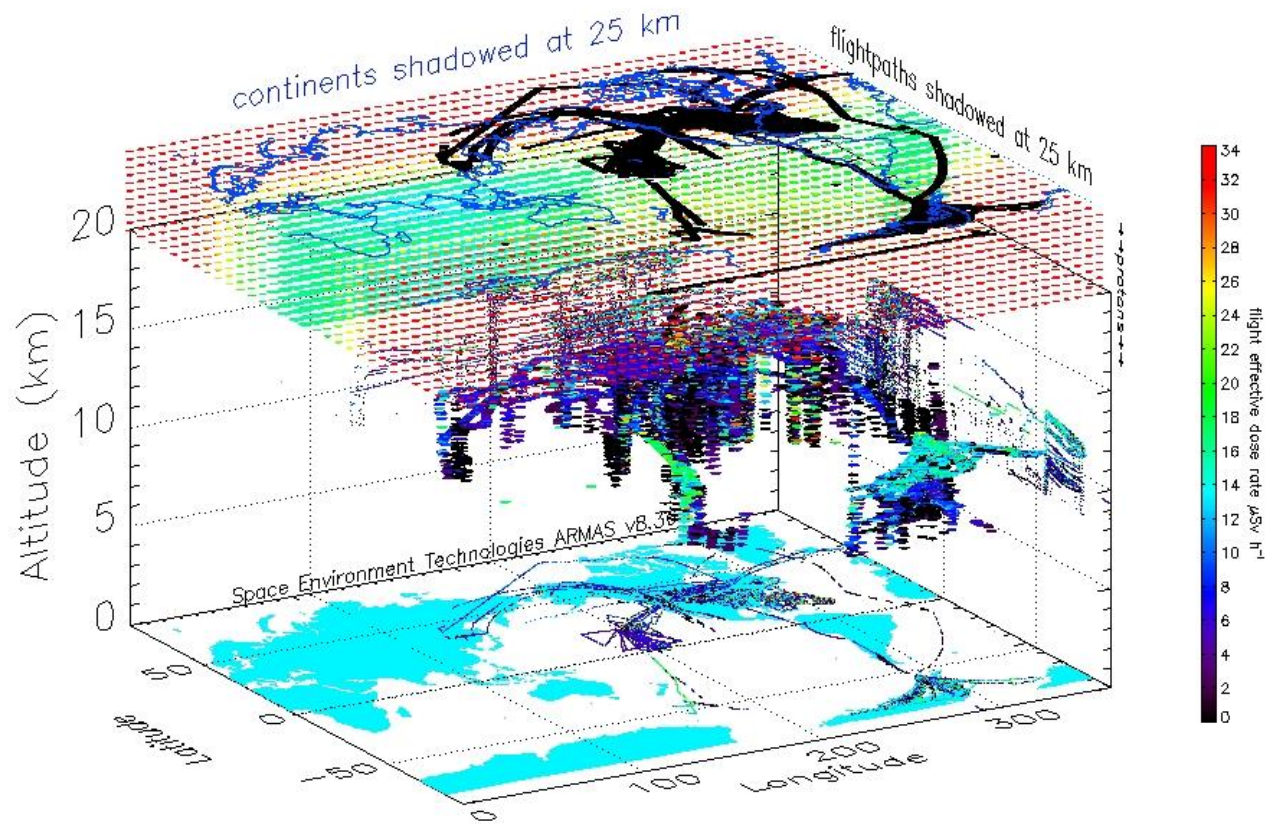
NSF G5



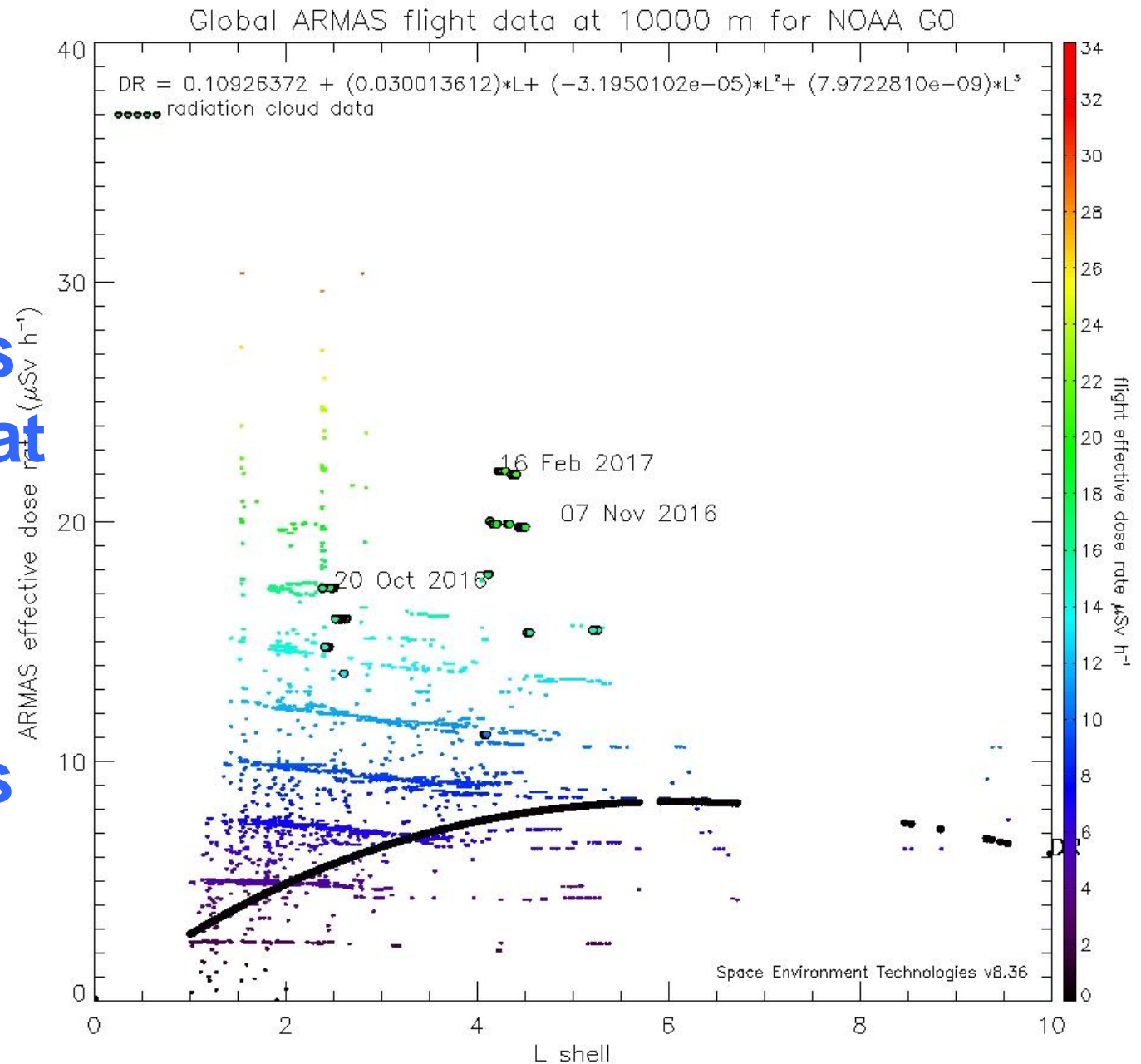
NOAA G4

ARMAS global dose rates >8 km
 total number of flights = 292
 total number of flight data records = 210650
 number of flight data records less than $10 \mu\text{Gy/h} = 91343$
 percentage of flight data records less than $10 \mu\text{Gy/h} = 43\%$

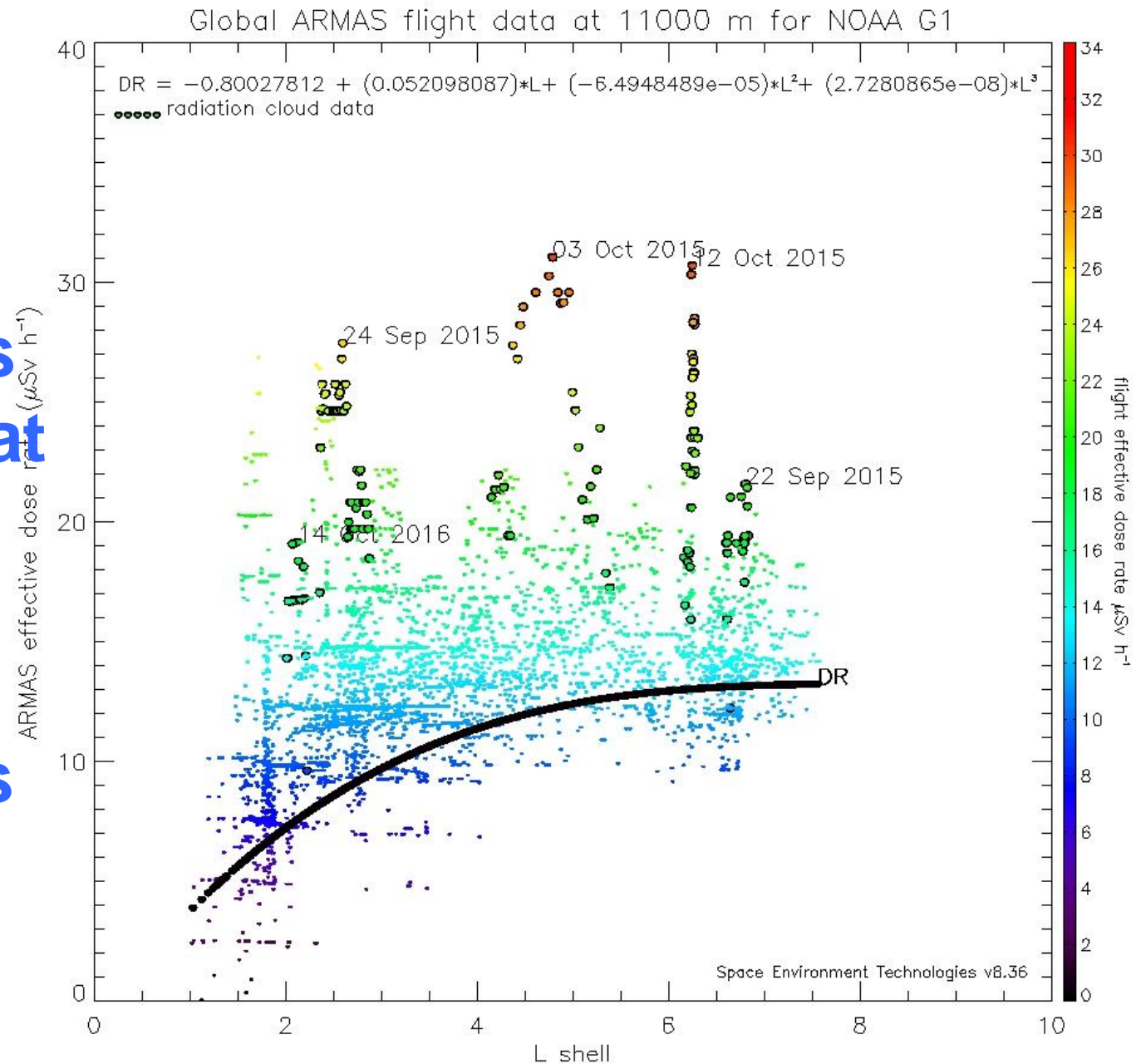
Global ARMAS dose rates above 8 km



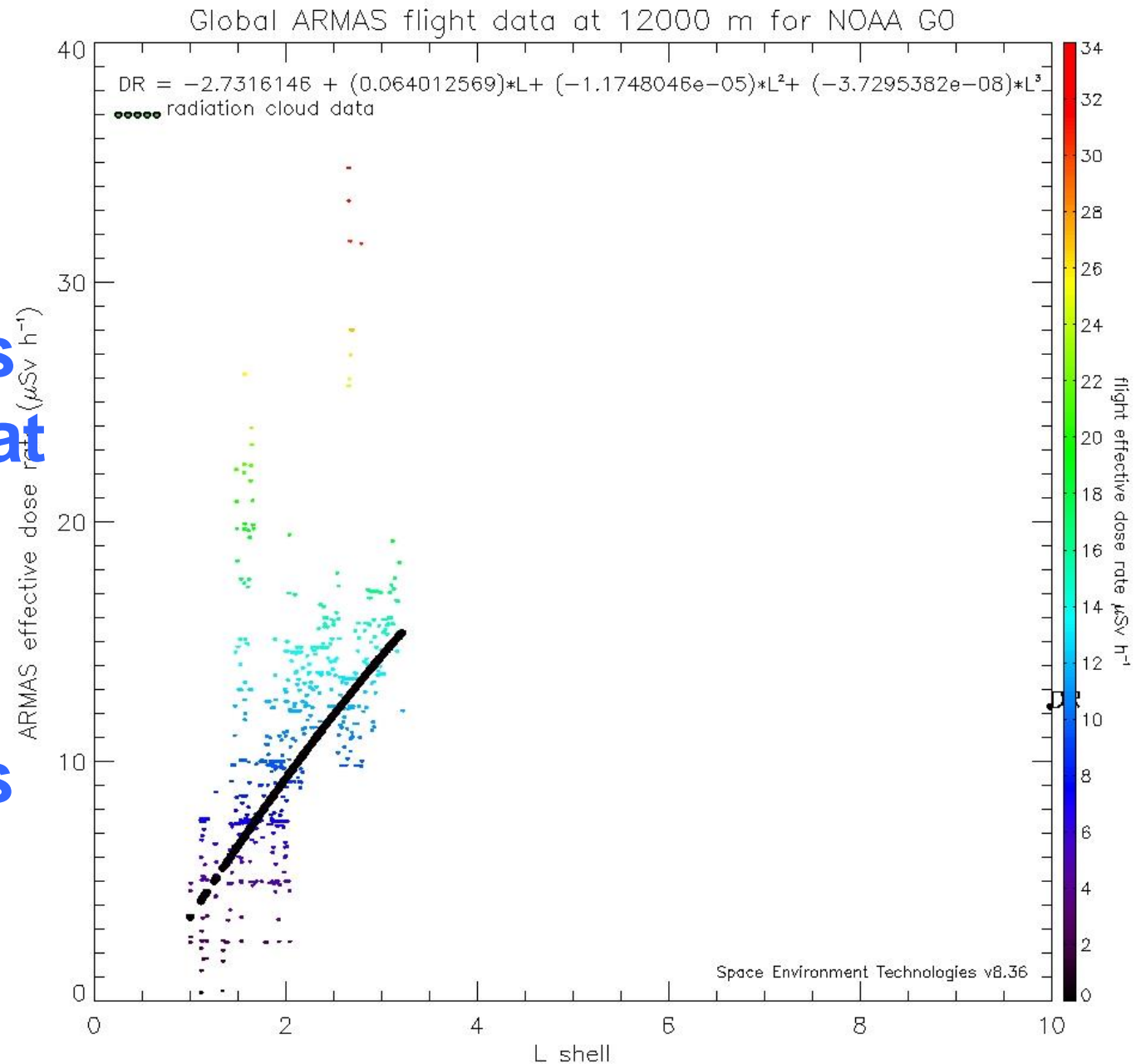
Dose rates vs. L shell at 10 km during NOAA G0 conditions



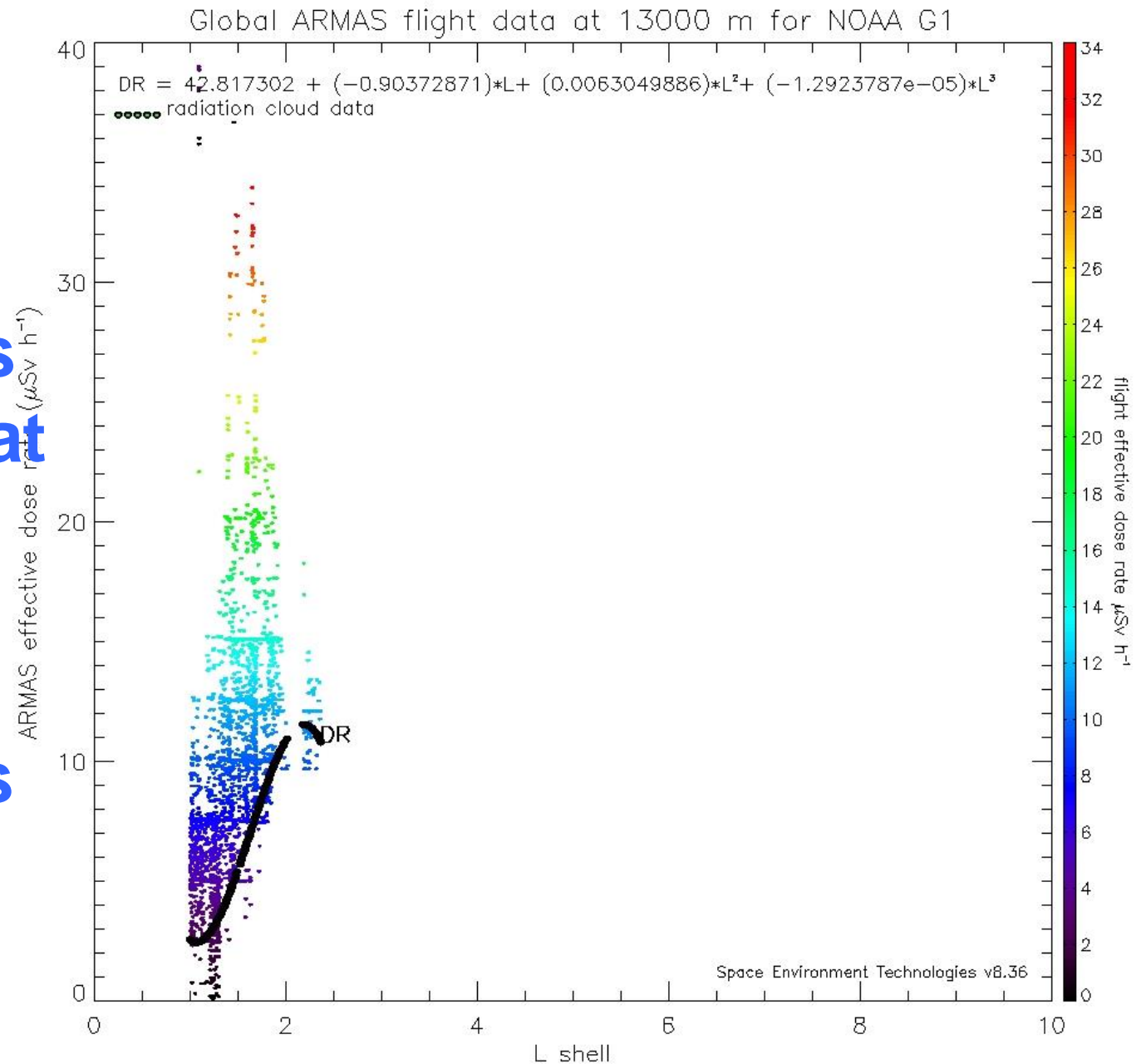
Dose rates vs. L shell at 11 km during NOAA G1 conditions

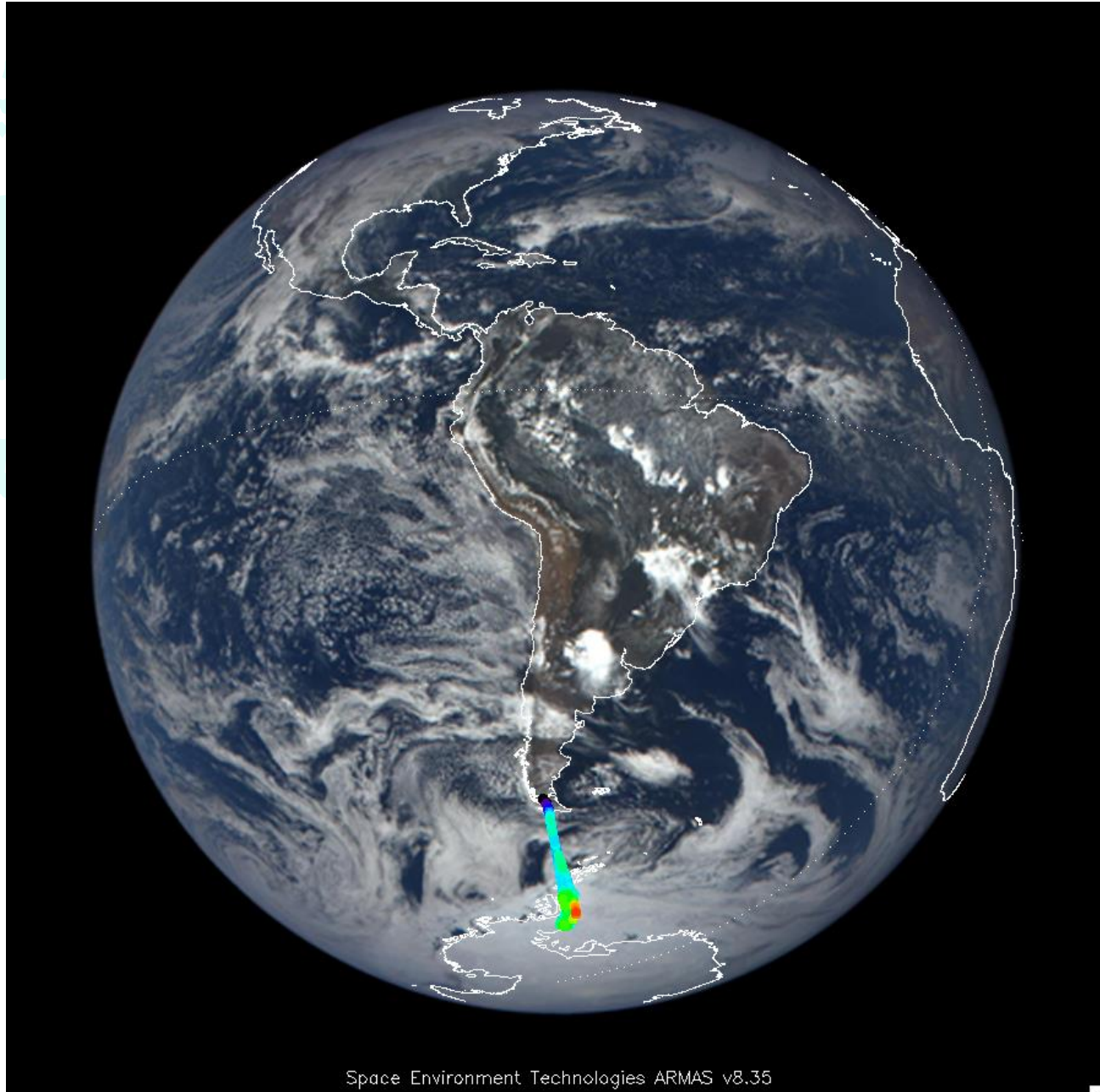


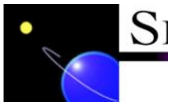
Dose rates vs. L shell at 12 km during NOAA GO conditions



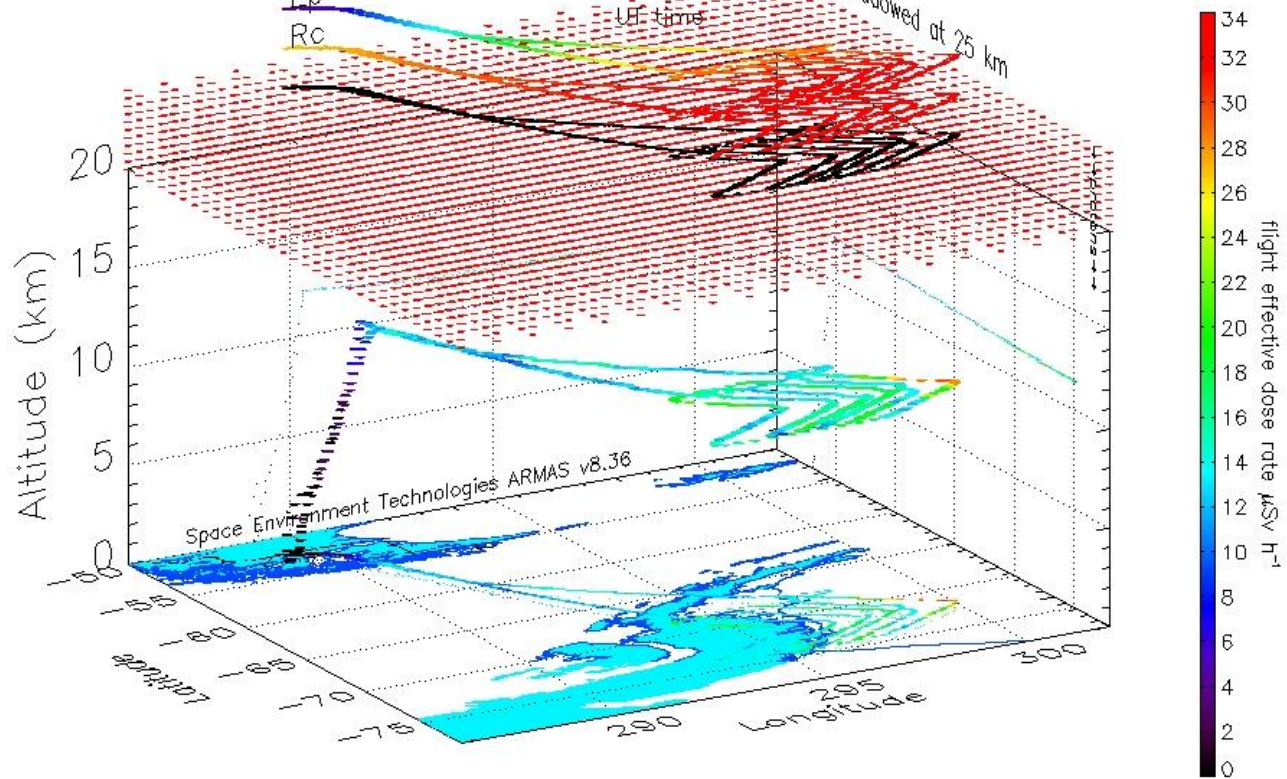
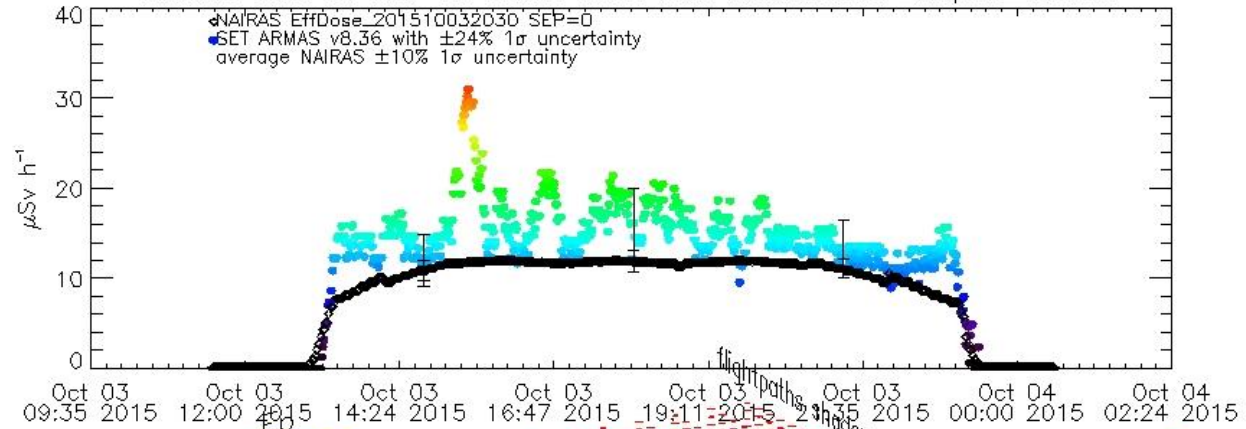
Dose rates vs. L shell at 13 km during NOAA G1 conditions







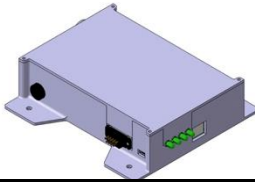
ARMAS FM2 GV NSF effective dose rate ARMAS_dirIP_Report_43550



Kp=3 with proton cutoff energy (E_p in MeV) at altitude (courtesy SSSRC)

5000 4000 3000 2000 1000 0
Kp=3 with cutoff rigidity (R_c) >20 km (GV: red = greatest dose hazard; courtesy SSSRC)

25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5



World View ARMAS FM4

Deployment

- Stratospheric balloon flights starting in 2018 under MOU between World View and SET
- Data will be extended to ~40 km as a World View pathfinder payload





ARMAS FM6 on business jets in 2017

- FM6 has a micro dosimeter, GPS, micro SD data logger, Bluetooth and battery and/or AC power in a size similar to a smart phone
- All altitude ranges and all sources of radiation
- **Personal dose exposure reported around the world** providing situational awareness
- **Provides management options for rad flight events**
- FAA compliant (stand-alone unit with no attachment to plane)





NASA WHAATRR Glider ARMAS

FM7

Deployment

- Data will be captured on balloon ascent to 30 km (100,000 ft.) and on glider descent to Edwards AFB
- Small form-factor





2017 ARMAS activities

- ✓ **Continued research flights with existing instruments: FM1, FM2A/B, FM3, FM5A/B:** participate in global scientific campaigns
- ✓ **Build and deploy FM4 and FM7:** make stratospheric balloon flights on World View and NASA AFRC WHAATRR Glider vehicles
- ✓ **Build and deploy FM6:** produce commercial business jet instrument to extend number of instruments in fleet to >100
- ✓ **Integrate USAF REACH data:** dose measurements start with 3 Teledyne TID detectors in LEO on Iridium hosted payloads (Jan 2017)
- **Complete NAIRAS-ARMAS data assimilation:** take the step from global radiation climatology to global radiation weather
- ✧ **10 daily flight measurements will move community to STEP 3 (monitoring)**
- ✧ **100 daily flight measurements will move community to STEP 4 (specification and forecast)**